



The Radio Amateur Satellite Corporation



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AMSAT

NxtGen Crystal Radio

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NxtGen Crystal Radio

- AMSAT-NA Education Goals
 - Benefit Youth through STEM Education
 - Raise awareness through Educational Outreach
 - ARISS
 - AMSAT-Edu
 - Develop Partnerships with K-16 institutions for NASA's CubeSat Launch Initiative (CSLI) Program
 - Maintain CubeSat Simulators / Mechanical Mock up for Educators and Area Coordinators
- Keep Amateur Radio In Space



NxtGen Crystal Radio

- Only one person responded that their Crystal Radio also transmitted (thank you Burns Fisher, W2BFJ)
- If I would have asked this question 50 years ago, I wonder what the answer would have been?
- It likely would have been –
- “I built a Crystal Radio Receiver” or “I built a Spark Gap Transmitter”

NxtGen Crystal Radio

- So what is today's Crystal Radio Receiver?
- That depends on today's Youth and where their interests lay
 - But it better be Digital
 - One or more of what I call "The Big 3"
 - Robotics
 - Programming (like Ras Pi)
 - Space
 - And it better have an App





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- So for AMSAT-NA Education that created a challenge
- The goal was to educate by “kit building” and have that benefit AMSAT and STEM education
- I also had a deadline
- HamVention 2017
 - Carole Perry’s (WB2MGP) Instructor’s Forum
 - With a developed “Kit”





NxtGen Crystal Radio

- So what is today's Crystal Radio?
- The components would probably need to be:
 - Software Defined Radio (SDR)
 - Digital
 - Programmable
- Antenna with Coaxial cable
 - Space (Tuned for Satellite Frequency Band)

NxtGen Crystal Radio

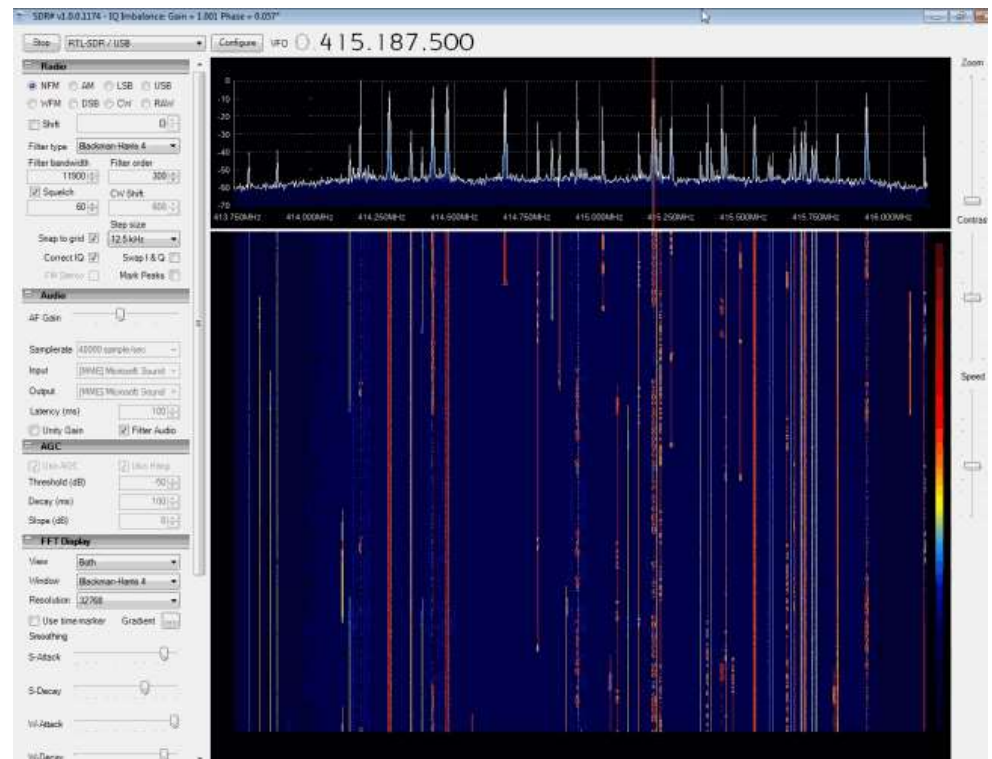
➤ Software or the “App”

➤ SDR

- Digital
- Programmable

➤ FoxTelem

- Digital
- Programmable
- Space



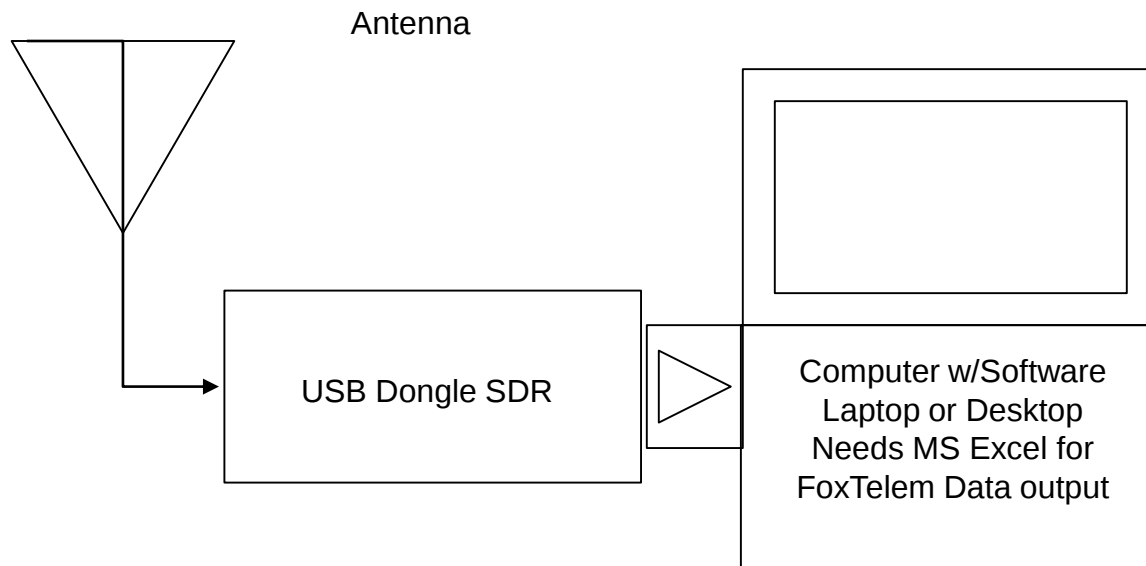


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- Additional Parameters
 - Cost Efficient (Need to provide 10 – 12 kits)
 - Compact Size (must be classroom friendly)
 - Reasonable Performance
 - Unattended Configuration

- Beginning Assumptions
 - Hard Part
 - SDR Choice
 - Easy Part
 - Antenna Selection
 - Simple Software Porting of SDR to FoxTelem Program

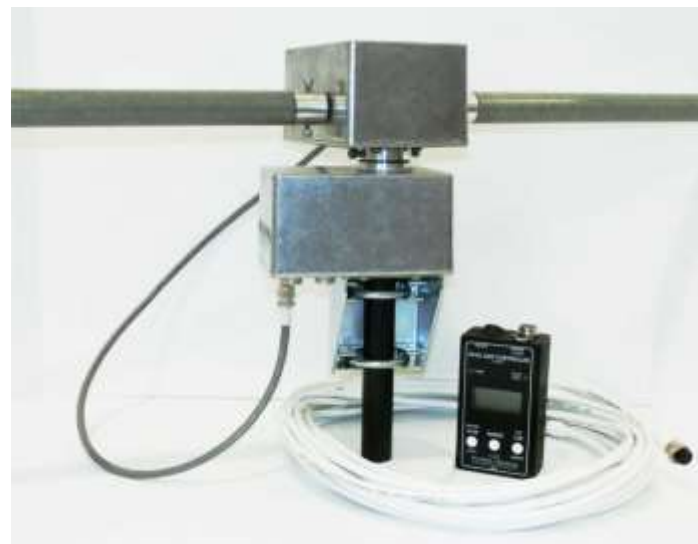
NxtGen Crystal Radio



NxtGen Crystal Radio Basic Design

NxtGen Crystal Radio

- The Easy Part
- Antenna Selection
 - M² Antennas EB-144 Eggbeater
 - Quadrifilar Helicoidal
 - Arrow w/Rotator
 - Elk w/Rotator
 - Tape Measure w/Rotator
- Eliminated before Starting
 - Arrow w/Rotator
 - Elk w/Rotator
 - Tape Measure w/Rotator
- Additional Rotator/Cabling/Control Software Required
 - Cost Efficient – No (10 x \$300(minimum) = \$3000)



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➤ M² Antennas EB-144 Eggbeater

- 40" in diameter
- 6 dBi Gain with reflector kit
- List Price \$273

➤ Benefits

- Omni/Right Hand Circular Directional Antenna
- Reasonable Performance
- Unattended Configuration

➤ Disadvantages

- Cost Efficient – No ($10 \times \$273 = \2730)
- Compact Size (must be classroom friendly) – Very Large



NxtGen Crystal Radio

- Quadrifilar Helicoidal (QFH)
- Benefits
 - Omni Directional Antenna
 - Excellent Performance designed for satellites
 - Unattended Configuration
 - Cost Efficient
- Disadvantages
 - Compact Size (must be classroom friendly) – Long
 - 27.1" in Vertical Height
 - Semi-Complex Construction (Would need to be shipped Assembled) Balun Required
- Excellent Design Calculator at <https://www.jcoppens.com/ant/qfh/calc.en.php>





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- Quadrifilar Helicoidal (QFH) consists of two loops
 - To obtain a circular polarization, it is necessary that the currents in both loops have a phase difference of 90 degrees. Though it is possible to make the phase difference with a phasing line (which is popular with the turnstile antenna), the most popular solution for the QFH is to use different loop sizes. This causes the current to be inductive in one, and capacitive in the other. Though the currents in both loops are reactive, connecting them in parallel causes the feed point, at the top, to be at nearly 50 Ohm, resistive.
 - The only problem remaining, is that the feed point, as with most antennas, is symmetrical. This means we shouldn't connect a coax cable (asymmetric) at this point. Though the antenna will be adapted, currents on the outside of the cable will offset the radiation pattern of the antenna.



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- Quadrifilar Helicoidal (QFH) several feed point solutions exist:
 - **Transformer**
 - We could install a balun transformer at the top, but simple baluns transform impedance too - we want to maintain 50 Ohms.
 - **Choke**
 - Applying a couple of turns to the coax cable at the top will make the braid act as an RFC choke and block outside currents.
 - **Infinite balun**
 - Feeding the cable through one of the loop sides, will form an 'infinite balun'.
 - **Preamplifier**
 - Another - elegant - solution would be to install a preamplifier at the top, and design it for symmetrical input. As far as its know, none are on the market, so we'd have to make our own...



NxtGen Crystal Radio

- Quadrifilar Helicoidal (QFH) Feed point Solutions Con't
 - Finally, using simply two loops, without the strange 'twist' which is so typical of the QFH, would generate a much more directional (vertical) radiation pattern. Also, the polarization would turn to linear near the horizon. The 'twist' generates the desired hemispherical pattern, which permits us to hear from horizon to horizon.
- Choke Baluns
 - A simple solution for eliminating the exterior cable currents, is to wind the cable a number of times around the vertical support, making the outside act as an RF choke (inductor). The diameter should be as small as is practical, to reduce radiation as much as possible. The number of turns depends on the diameter, of course, but the inductance should be large enough (compared to 50 Ohm) to reduce the outside currents.
 - The windings should be as near to the top as possible, to reduce the length of the radiating parts.



NxtGen Crystal Radio

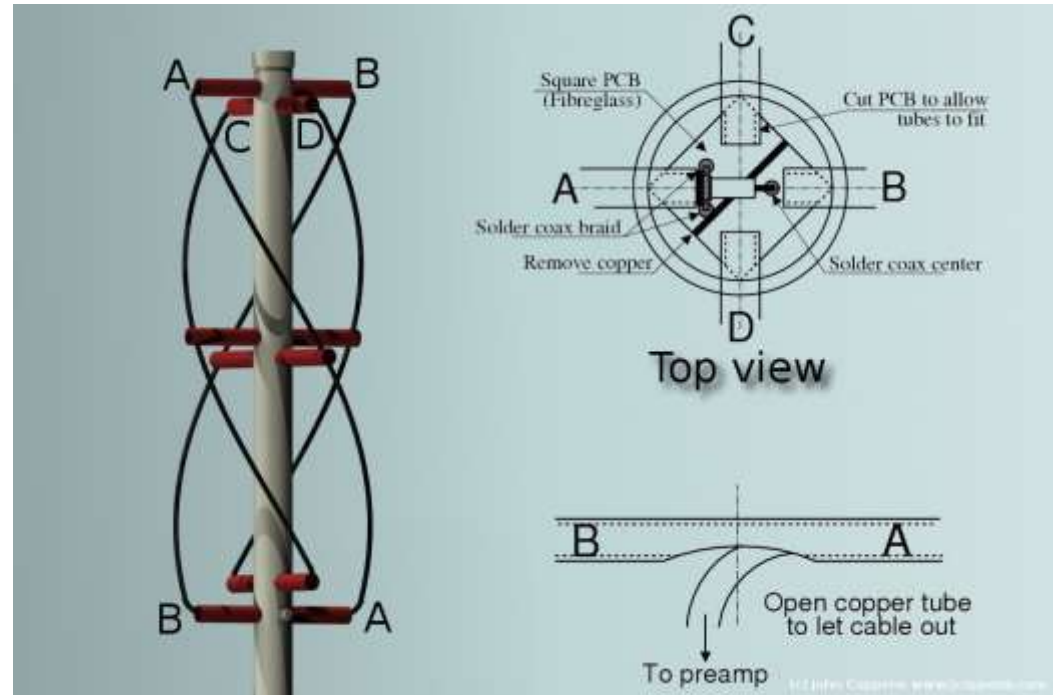
- Quadrifilar Helicoidal (QFH) Feed point Solutions Con't
 - Infinite Baluns
 - Many questions arise about the infinite baluns... The impedance at the top is the one we want at the bottom too. So we cannot tolerate impedance transformation through the balun. This means we *have* to use a cable with the same impedance - else there would be a transformation!
 - For UHF and SHF work, the most practical solution is probably to use coax cable for the actual antenna itself. For lower frequencies, we should use tubing, and feed a 50 Ohm cable through it.
 - Part of the infinite balun principle, is the cable's braid should be connected to the antenna at the bottom center. In practice it has been difficult to detect much difference.
- Excellent QFH resources at
<https://www.jcoppens.com/ant/qfh/index.en.php>

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Choke balun

*ON7EQ's QFH with
balun*



Infinite balun

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- Quadrifilar Helicoidal (QFH) is an excellent additional project for NxtGen Crystal Radio
 - All QFH Resources from <https://www.jcoppens.com/ant/qfh/index.en.php>





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- The Easy Part becomes the Hard Part
 - All antennas options were eliminated
- AMSAT website to the rescue
- Station and Operating Hints
 - <https://www.amsat.org/station-and-operating-hints/>
- An EZ-Lindenblad Antenna for 2 Meters
 - <http://www.amsat.org/wordpress/wp-content/uploads/2015/08/An-EZ-Lindenblad-Antenna-for-2-Meters2.pdf>
- Antenna developed for Fox CubeSats by Anthony Monteiro, AA2TX (SK)



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- An EZ-Lindenblad Antenna for 2 Meters
 - Designed as an airport antenna in the 1930's
 - RHCP
 - Omni directional
 - With most of its gain at low elevation angles, it is ideal for accessing low earth orbit (LEO) Amateur Radio satellites.
 - Because it is omnidirectional, it does not need to be pointed at a satellite so it eliminates the complexity of an azimuth/elevation rotator system.
 - Meets Design Parameters
 - Cost Efficient
 - Compact Size (must be classroom friendly)
 - Reasonable Performance
 - Unattended Configuration



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- This type of antenna was devised by Nils Lindenblad of the Radio Corporation of America (RCA) around 1940.¹
 - His idea was to employ four dipoles spaced equally around a $\lambda/3$ diameter circle with each dipole canted 30° from the horizontal. The dipoles are all fed in phase and are fed equal power. The spacing and tilt angles of the dipoles create the desired antenna pattern when the signals are all combined.
 - ¹ G. Brown and O. Woodward, Jr., *Circularly Polarized Omnidirectional Antenna*, *RCA Review*, Vol 8, no. 2, Jun 1947, pp 259-269.



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- After World War II, George Brown and Oakley Woodward, also of RCA, were tasked with finding ways to reduce fading on ground-to-air radio links at airports.²
 - These links used linearly polarized antennas. The maneuverings of the airplanes often caused large signal dropouts if the antennas became cross-polarized. Brown and Woodward realized that using a circularly polarized antenna at the airport could reduce or eliminate this fading so they decided to try Lindenblad's TV antenna concept.
 - ² G. Brown and O. Woodward, Jr., *Circularly Polarized Omnidirectional Antenna*, *RCA Review*, Vol 8, no. 2, Jun 1947, pp 259-269.



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- Brown and Woodward designed their antenna using metal tubing for the dipole elements.
 - Each dipole element is attached to a section of shorted open-wire-line, also made from tubing, which serves as a balun transformer. A coaxial cable runs through one side of each open-wire-line to feed each dipole. The four coaxial feed cables meet at a center hub section where they are connected in parallel to provide a four-way, in-phase power-splitting function. This cable junction is connected to another section of coaxial cable that serves as an impedance matching section to get a good match to 50 Ω .



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- While the Brown and Woodward design is clever and worked well, it would be quite difficult for the average ham to duplicate.
 - The major cause of the difficulty in designing and constructing Lindenblad antennas is the need for the four-way, in-phase, power splitting function. Generally we want to use 50 Ω coaxial cable to feed the antenna, we have to somehow provide an impedance match from the 50 Ω unbalanced coax to the four 75 Ω balanced dipole loads.
 - Previous designs have used combinations of folded dipoles, open-wire lines, twin-lead feeds, balun transformers and special impedance matching cables in order to try to get a good match to 50 Ω . These in turn increase the complexity and difficulty of the construction.

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➤ The EZ-Lindenblad

- An antidote to these difficulties is the EZ-Lindenblad.
- The key concept of the EZ approach is to eliminate anything that is electrically or mechanically difficult, leaving only things that are easy. This leads to the idea of just feeding the four dipoles with coax cable and soldering the cables to a connector with no impedance matching devices at all. This would certainly be easy but we also want the antenna to work! Without the extra impedance matching devices, how is it possible to get a good match to $50\ \Omega$?



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➤ The EZ-Lindenblad

- If we could get each of the four coax feed cables to look like $200\ \Omega$ at the connector, then the four in parallel would provide a perfect match to $50\ \Omega$.
 - We could do this if we used quarter-wavelength sections of $122\ \Omega$ coax to convert each $75\ \Omega$ dipole load to $200\ \Omega$. Unfortunately, there is no such coax that is readily available.
 - But we can accomplish the same thing with ordinary $75\ \Omega$, RG-59 TV type coax if we run the cable with an intentional impedance mismatch. By forcing the standing wave ratio (SWR) on the cable to be equal to $200/75$, or about $2.7:1$, we can make each cable look exactly like $200\ \Omega$ at the connector as long as we make them the right length.



NxtGen Crystal Radio

➤ The EZ-Lindenblad

- It is easy to make the SWR equal 2.7:1 by just making the dipoles a little too short for resonance.
 - An EZNEC antenna model can be used to determine the exact dipole dimensions. ³
 - The conversion from the balanced dipole load to the unbalanced coax cable can be painlessly accomplished by threading each cable through an inexpensive and readily available ferrite sleeve making essentially a choke balun.
 - The only remaining issue is the required length of the feed cables, and this can be easily determined using a Smith Chart.
 - ³ EZNEC+ V4 antenna analysis software by Roy W. Lewallen, W7EL, available from www.eznec.com.



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- The required length of $75\ \Omega$ coax to provide a 200Ω load was determined with a Smith Chart.
 - An EZNEC antenna model was used to simulate cutting the dipole lengths until the SWR on the line reached 2.7:1. The model showed that the dipole load impedance would then be $49 - j55\ \Omega$.
 - The length of the coaxial line calculated to $0.374\ \lambda$.
 - Designing for a center frequency of 145.900 MHz, optimizes performance in the satellite sub band.
 - At 145.9 MHz, a wavelength is about 81 inches and since the coax used has a velocity factor of 0.78, we need to make the feed cables $81 \times 0.374 \times 0.78 = 23.6$ inches long.



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- EZ-Lindenblad Radiation Pattern favors the lower elevation angles.
 - The -3 dB points are at 5° and 25° with the maximum gain of 4.8 dBic (with respect to an isotropic circularly polarized antenna) at around 13° .
 - This is an excellent pattern for accessing LEO satellites.
 - Most of the satellite pass elevations will be in this range and it is also the elevation at which the satellite provides the best chance for DX contacts.
- Higher elevation passes do not require as much gain.



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- Construction of the EZ-Lindenblad was basic.
 - Cut the aluminum tubing to length.
 - Mount the cross boom tubing on the angle bracket.
 - After constructing the prototype, the angle bracket (mounting pole location) was centered by slightly offsetting the cross boom mounting holes. Flat head bolts were also used to keep angle bracket flat against the mounting pole.
 - Assemble and mount the dipoles on the cross booms at 30° angle.
 - Cut, trim, assemble, and solder RG-59 coax into a phasing harness with N connector and ferrite choke.

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Various Construction Photos of EZ-Lindenblad Antenna





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- The EZ-Lindenblad
 - The assembled antenna measures about 15" in height and 26" in width. To ship 12 assembled antennas would be approximately two shipping pallets by truck freight.
 - An Engineering exercise in packaging began.
 - The antennas were mechanically disassembled. The cross booms, assembled dipoles, and angle brackets were fitted into 36" long x 3" diameter mailing tubes. Colored dots were used to ease in re-assembly.
 - All bolts, screws, and phasing harness were placed into zip lock bags and instructions to assemble were put into a small box with the rest of the NxtGen Crystal Radio kit.

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Assembly / Packaging Photographs

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- The EZ-Lindenblad
- Test Results



Packaging Results



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Assembled EZ-Lindenblad
Antenna at Hamvention
2017

NxtGen Crystal Radio

- The Hard Part becomes the Easy Part
 - Remember those Beginning Assumptions
 - Hard Part
 - SDR Choice
 - Easy Part
 - Antenna Selection (**HARD PART**)
 - Simple Software Porting of SDR to FoxTelem Program
- Software Defined Radio Choices
 - RTL-SDR \$20
 - SDRPlay RSP1 \$90
 - FunCube Pro+ Dongle £124.99 or \$163



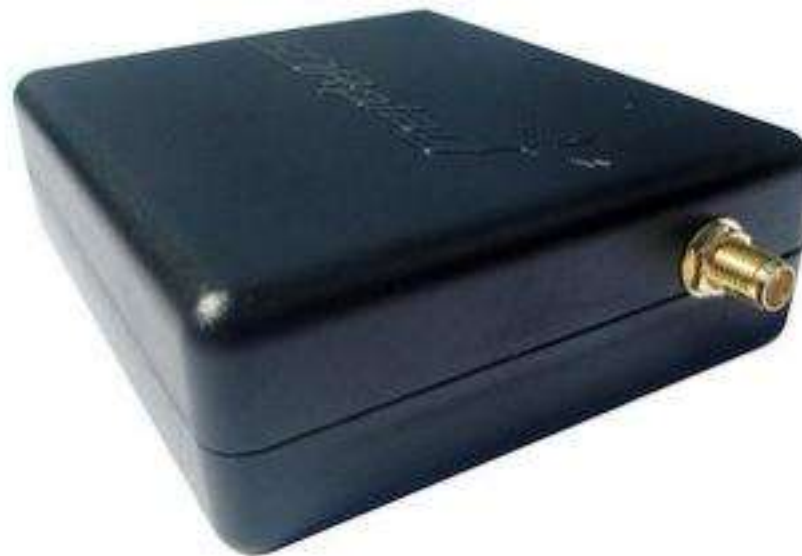
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- The Hard Part becomes the Easy Part
 - Eliminated before Starting
 - FunCube Pro+ Dongle £124.99 or \$163
 - Cost Efficient – No (10 x \$163(minimum) = \$1630)
 - The FunCube Pro+ is an excellent SDR for FoxTelem.
 - A major benefit is the Fox Telem software is developed to recognize the FunCube Pro+ dongle as an input.



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- SDRPlay RSP1 \$90
- \$90
- Benefits
 - Cost Efficient
 - Unattended Configuration
 - Reasonable Performance
 - Low noise floor
 - 10kHz to 2 GHz
 - FM, TV, WeFAX, etc.
- Disadvantages
 - Compact Size – Requires USB-B Cable



NxtGen Crystal Radio

➤ RTL-SDR

➤ \$20

➤ Benefits

- Cost Efficient
- Compact Size
- Unattended Configuration
- 52 MHz – 2200 MHz
- FM, TV, WeFAX, etc.

➤ Disadvantages

- Reasonable Performance
 - Marginal
- Noise Floor $\sim$ -60dB



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- Methods to improve RTL-SDR performance
- JaniLabs RTL-SDR Pre-Amplifier
 - Operating Frequency: 1MHz to 3GHz
 - RF Gain adjustable: -20dB to +19dB
 - Noise: 1.9-2.1dB
 - Connectors: SMA Female Jack





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- The Cost Analysis
 - RTL-SDR + SMA connector + JaniLabs Pre-Amp + Power Supply
 - $\$20 + \$5 + \$20 + \$20 = \$65$
 - SDRPlay RSP1 + USB-B cable
 - $\$90 + \$5 = \$95$
 - FunCube Dongle Pro+
 - \$163
- RTL-SDR selected based on lowest cost, moderate performance, and easy availability



NxtGen Crystal Radio

- The Easy Part becomes the Hard Part (Part 2)
 - Remember those Beginning Assumptions
 - Hard Part
 - SDR Choice (**EASY PART**)
 - Easy Part
 - Antenna Selection (**HARD PART**)
 - Simple Software Porting of SDR to FoxTelem Program
- The “App”
 - SDR Software
 - FoxTelem Software

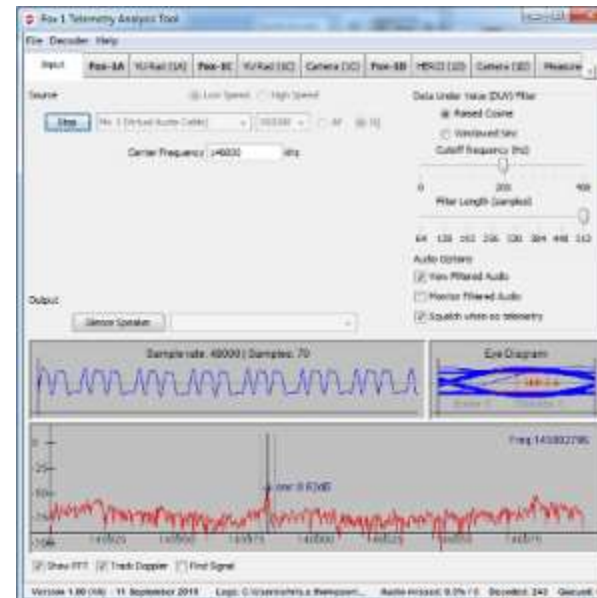


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- The FoxTelem Software
 - Download from AMSAT-NA website
 - <https://www.amsat.org/foxtelem-software-for-windows-mac-linux/>
 - We get some ideas on SDR configuration from the instructions on using the FunCube Pro+ Dongle
 - A software defined radio is a better choice because we get no filtering of the low frequency audio. The Funcube Dongle, for example, can receive the telemetry and pass the IQ baseband audio untouched to FoxTelem.

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- You have two choices to set this up.
 - Either receive the audio in your favorite SDR software and feed the demodulated FM audio to the telemetry decoder
 - Or use the IQ demodulation in the telemetry decoder itself.
- Both should work.





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- Here are the advantages of using FoxTelem's IQ demodulator:
 - Advantages
 - FoxTelem will find the satellites signal when it appears and will follow the Doppler. You do not need a separate application to set the frequency assuming it is in the pass band of the SDR.
 - FoxTelem will measure the parameters about the received signal such as Signal to noise ratio (SNR) and Time of Closest Approach (TCA), which AMSAT would like to collect and analyze.
 - You don't need to use another piece of software, such as Virtual Audio Cable, to connect the two programs. Or feed the audio out of the computer and back in again with a physical cable.



NxtGen Crystal Radio

- Here are the disadvantages of using FoxTelem's IQ demodulator:
 - Disadvantages
 - A separate SDR program may have better capabilities than the SDR in the Telemetry Decoder.
 - Your existing SDR may already be configured to work with Doppler correction software and the rest of your ground station
 - FoxTelem can be more compute-intensive than some other SDR programs and may not work as well on slower computers
 - Remember all these caveats are for a selected input in the FoxTelem software.
- How do we connect a wide band SDR?



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- In the past, we simply would have made an interface cable.
 - Radio to decoder, need an adaptor cable
- The same is true today only Digital
 - The RTL-SDR and SDRPlay are receivers with a digital interface software for tuning.
 - The RTL-SDR also needs some software configurations
 - This is accomplished by using SDR# software.
- There are some very good RTL-SDR and SDR# YouTube videos – just Google them!

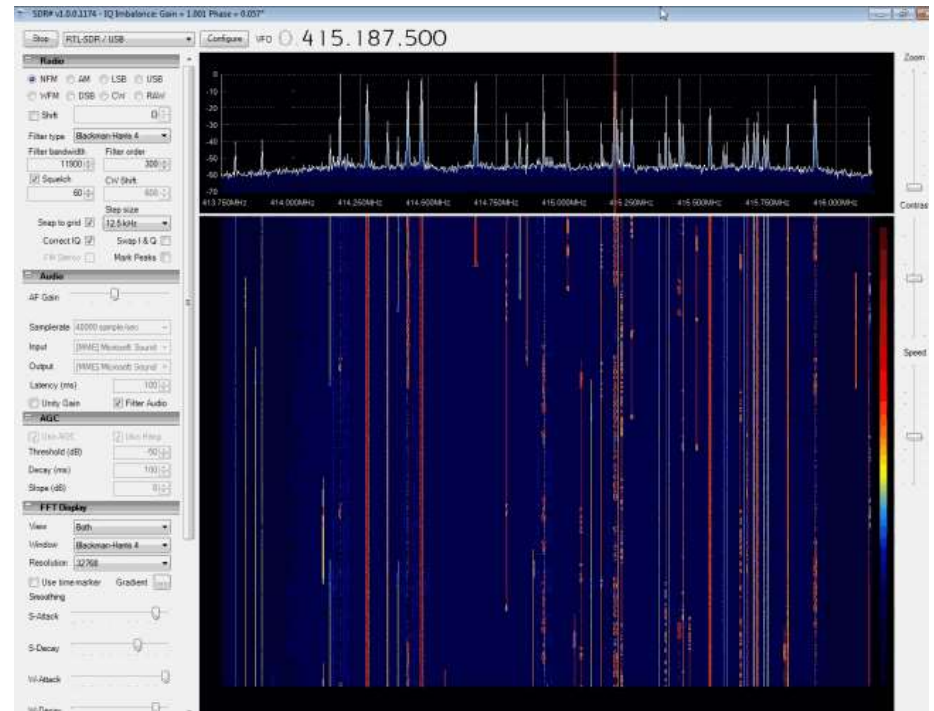


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- SDR# (Radio) + ? (Cable) + FoxTelem (Decoder)
 - What is used for the cable?
 - Two Choices
 - Virtual Audio Cable Software
 - <http://software.muzychenko.net/eng/vac.htm>
 - VB Audio Cable
 - <https://www.vb-audio.com/Cable/index.htm>
 - Both are fairly system specific so configurations are customized.

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- SDR# + VAC + FoxTelem = “App”
 - SDR#
 - Receiver Software
 - Virtual Audio Cable or VB Audio Cable
 - Takes the output from SDR#
 - Feeds to the input of FoxTelem
 - FOXTelem Software
 - Data Under Voice (>300Hz) Telemetry for all Fox Satellites



NxtGen Crystal Radio

- The Easy Part becomes the Hard Part (Part 2)
 - Remember those Beginning Assumptions, again
 - Here's the Reality Check
 - Hard Part
 - SDR Choice (**EASY PART**)
 - Easy Part
 - Antenna Selection (**HARD PART**)
 - Simple Software Porting of SDR to FoxTelem Program (**EASY/HARD PART**)



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- AMSAT Satellite Ground Receiving Station
 - RTL-SDR
 - JaniLabs RTL-SDR PreAMP
 - EZ-Lindenblad Antenna
 - FOXTelem Software
 - Total Cost = \$180 each



NxtGen Crystal Radio

- Future Experimentation
 - Antenna Designs
 - Quadrifilar Helicoidal
 - 70cm Parasitic Lindenblad Omni Antenna
 - <http://www.amsat.org/wordpress/wp-content/uploads/2014/01/70ParaLindy.pdf>
- EXCEL Data to NASA GMAT
 - Real Mission Data ported to a Graphic Model
 - <http://gmatcentral.org/>



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➤ Future Experimentation

➤ LimeSDR \$299

➤ LimeSDR is an open source, apps-enabled software-defined radio (SDR) platform that can be used to support just about any type of wireless communication standard; it can transmit and receive UMTS, LTE, GSM, LoRa, Bluetooth, Zigbee, RFID, and Digital Broadcasting

➤ <https://myriadrf.org/projects/limesdr/>





For More Information

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